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MASS TRANSFER INTO NON-NEWTONIAN SYSTEMS

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MASS TRANSFER INTO NON-NEWTONIAN SYSTEMS

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STATEMENT OF PROGRESS

A. Theses and Publications

1. Thesis - This report

The following thesis has been accepted and published during the past year.

a. "Mass Transfer into Non-Newtonian Fluids" by M.J. Bellanca, Thesis, Master of Science, Cornell University, Ithaca, N.Y., February, 1964.

2. Publications - This report

The following article has been published since the last report.

a. "Capillary Versus Pipeline on Determining Flow Behavior of Digested Sewage Sludge," by V.C. Behn and R.M. Shane, Water and Sewage Works, 110, No. 7, pp. 272-274, July, 1963.

Ten copies of this paper have been forwarded to USPHS.

In addition there is one report made informally. That is

b. "Diffusion in Slurries" by A.J. Shuckrow Department of Sanitary Engineering, Cornell University, Ithaca, N.Y., August 15, 1963.

3. Thesis and Publications - Previous reports

The following have been reported in previous progress reports.

a. "The Determination of the Flow Parameters of Waste Sludges by Means of a Capillary Viscometer" by J.M. Sirman, Thesis, B.S. with Distinction in Civil Engineering, University of Delaware, Newark, Delaware, July, 1960.

b. "Fundamental Rheological Properties of Sewage Sludges," by D.R. Tatman, Thesis, Master of Civil Engineering, University of Delaware, Newark, Delaware, June, 1961.

c. "The Effect of Shear Rate Upon Diffusion Coefficients for Non-Newtonian Fluids" by H.E. Read, Thesis, Master of Mechanical Engineering, University of Delaware, Newark, Delaware, June, 1961.

d. "Flow Equations For Sewage Sludges" by V.C. Behn, Jour. Water Pollution Control Federation, 32, No. 7, p. 728, July, 1960.

e. "Determination of the Flow Parameters of Sludge" by J.M. Sirman, Water and Sewage Works, 107, No. 11, p. 417, November, 1960.

f. "Derivation of Flow Equations For Sewage Sludges" by V.C. Behn, Paper 2663, Jour. Sanitary Engineering Div., Proc. A.S.C.E., Vol. SA6, November, 1960.

g. "Application of the Method of Composition and Linear Regression Analysis to a Problem Involving a Pseudoplastic Suspension" by W.F. Ames and V.C. Behn, Trans. Society of Rheology, V, P. 53, 1961.

h. "Experimental Determination of Sludge-Flow Parameters" by V.C. Behn, Jour. Sanitary Engineering Div., Proc. A.S.C.E., 88, SA3, P. 39, May, 1962.

i. "Diffusion in Slurries and in Non-Newtonian Fluids" by S.B. Clough, H.E. Read, A.B. Metzner, and V.C. Behn, A.I.Ch.E., Jour., 8, No. 3, p. 346, July, 1962.

Articles d, g, and i were given at the respective annual convention.

B. Results Obtained

1. Objectives

The specific aim of the work was to investigate the role of mass-transfer into non-Newtonian systems of importance in water and waste treatment with particular emphasis as follows:

a. Determine whether the non-Newtonian parameters of suspensions containing tissue cells influence mass transfer under known shear in the same manner as has been found for systems of clay suspensions.

b. Determine whether known correlations for mass transfer in bubble aeration can be extended to the non-Newtonian case by making the appropriate corrections for the non-Newtonian case.

When the particular grant of which this is an extension was started it was concerned with non-Newtonian behavior per se. It was felt that over the years the publications cited in Section A3 of this report met the objectives of the research. The principal investigator then became interested in work as for example that of Gaden ("Aeration and Oxygen Transport in Biological Systems," Chapters 2-3 in Biological Treatment of Sewage and Industrial Wastes, by McCabe and Eckenfelder, Vol. 1, Reinhold, 1956). Gaden found that when 10 gram/liter of dry tissue was added to a broth the value of $k_L a$ was reduced to about 1/5 of its value. The above listed objectives are in effect an attempt to find out why this occurred.

2. Mass transfer under known shear.

When objective B.1.a. was postulated we had available the experience indicated by article A.3.i. In other words we started by finding out the role of shear rate in diffusion. Using clay particle suspensions, and benzoic acid diffusing from cast walls, we found that the diffusivity was not influenced by variation in the shear rate (A.3.c.). Accordingly we presented a theory which was an extension of the Eyring rate theory for mass transfer for calculating the diffusion into non-Newtonians (A.3.i.). This theory does not make a positive contribution of the suspended solids to the diffusion rate.

In order to meet objective B.1.a. we used the same apparatus. This consisted of a finger pump which pumped the cell suspension through a solid benzoic acid tube 1/2" in diameter and 18" long. The uptake of benzoic acid from the walls of the tube was measured by titration of the suspension.

A decision had to be reached upon the type of cells and we therefore selected an activated sludge developed from a

synthetic waste. We then decided to make the micro-organisms immobile with sodium azide. Unfortunately the sodium azide was found to have a distinct effect upon the solubility of benzoic acid. We therefore elected to use the activated sludge as found but in a state of endogenous respiration. Even with the precaution of endogenous respiration we found an increase of 3.1 g/l to 6.4 g/l of benzoic acid with from 0 to 22 g/l of activated sludge. In other words a distinct increase in benzoic acid solubility was noted with increase in activated sludge.

Apparently then we had a different phenomena in dealing with the activated sludge as against the clay particles. Consistent with the solubility data the activated sludge must have been adsorbing some benzoic acid. The series of diffusivities then run showed that the average value for diffusion into activated sludge was $.679 \times 10^{-4}$ cm^2/sec for benzoic acid. This contrasted with a value of 0.9×10^{-5} cm^2/sec for benzoic acid into water. The value in water is much lower than that for activated sludge. It is felt that this once again shows a chemical attraction.

The diffusivities were somewhat erratic but the trend is unmistakable. It would seem useful to run diffusivities of oxygen in activated sludge to confirm the results obtained with benzoic acid.

3. Mass Transfer - Buble Aeration

The second problem considered during the past year involved the bubble aeration of non-Newtonians. Since we could not use a suspension which would settle we decided to aerate a carboxy methyl cellulose (cmc) solution. Now if dimensional analysis is used then an equation of the type below applies to Newtonians

$$\frac{K_L d_B}{D_L} = \beta \left(\frac{d_B V_B \rho}{\mu}\right)^x \left(\frac{\mu}{\rho D_L}\right)^y$$

where K_L = diffusion coefficients

d_B = diameter of bubble

D_L = diffusivity

V_B = velocity of bubble

μ = viscosity of liquid

ρ = density of liquid

The values of β, X and y are given in the work by Redding (Sc.D. Thesis, MIT, 1942) as 0.014, 0.75, and 0.85 for laminar flow. If a substitution is made in the Reynolds Number $(\frac{d_B V_B \rho}{\mu})$ for non-Newtonian flow of the form $\frac{d_B^{n} V_B^{2-n} \rho}{K}$ and in the Schmidt Number $(\frac{\mu}{D_L})$ of the form $\frac{K(V_B/d_B)^{n-1}}{\rho D_N}$ we should be able to use the same correlation. In these equations n is t the flow behavior index, K is the consistency index, and D_N the diffusivity into non-Newtonians.

We set up a 5 1/2" I.D.x7' high lucite column with a gold and platinum Spinnerette in the bottom. The spinnerette was 1" in diameter and had 20 holes of 35 micron diameter. The bubble diameter and velocity were determined photographically. K_L was found using film theory calculations including the A/V (Area/Volume) ratio determined by measuring air input. Flow characteristics were determined with a capillary viscometer and the diffusivity was determined by direct proportion utilizing the equipment described in the previous section. It should be noted that the solutions tested were only slightly non-Newtonian, (n = .960 - 976). With greater non-Newtonian behavior the bubble behavior was quite erratic.

The results of the work indicated the Sherwood Number obtained by this means was invariably considerably lower than that calculated. On the other hand, if the Schmidt Number were left in its form calculated for water, agreement was quite good for the least non-Newtonian solution tested. For

the slightly greater non-Newtonian solution the calculated values using the Schmidt Number for water are a little low. We have not been able to resolve this as yet.

In any case the Schmidt Number is supposed to bring in the effect of diffusion. Apparently for the slightly non-Newtonian tested it had no effect whatsoever. The Reynolds Number however must be modified for non-Newtonian flow.

C. Plans For The Future

In essence the objectives have been largely met. In other words we now know that activated sludge systems are substantially different from clay suspensions in that they adsorb benzoic acid. Also in the bubble aeration of slightly non-Newtonian carboxy-methyl-cellulose solution with air only the Reynolds Number needs to be modified in computing Sherwood Number.

For the remainder of the project we expect to obtain additional information on diffusivity in clay slurries by finding out if there is any change in diffusivity with change in concentration. This will be taken at constant shear rate. A small positive change is expected.